# CHAPTER I: INTRODUCTION TO MODELING AND SIMULATION

University Center of AbdElhafid Boussouf, Mila
Master Artificial Intelligence and its applications
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Modeling and simulation
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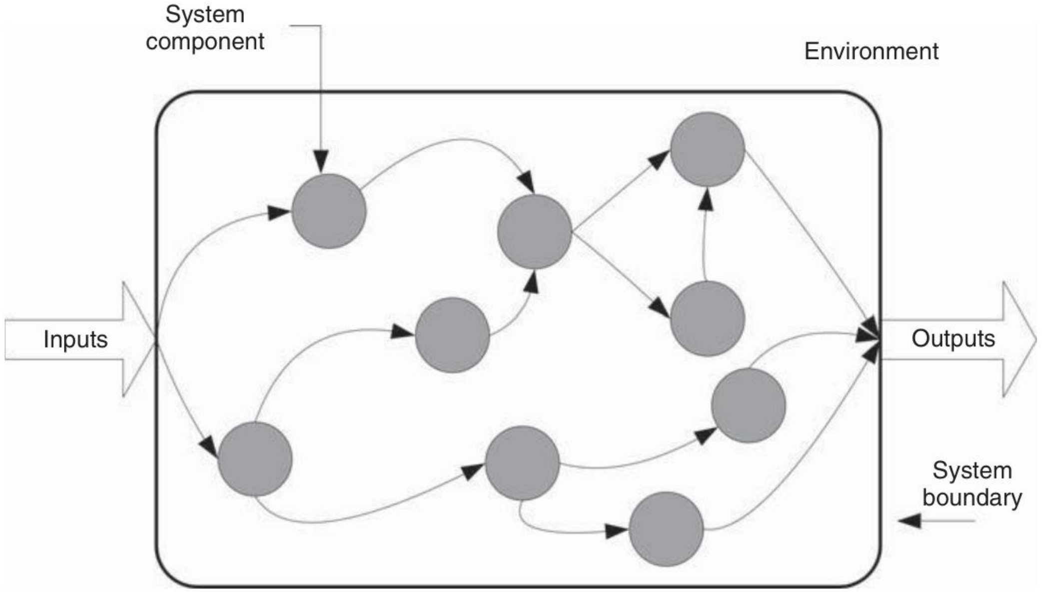
**Definition.** A system is defined to be a collection of entities, e.g., people or machines, that act and interact together toward the accomplishment of some logical end.

- A system is defined by:
  - The nature of its constituent elements;
  - The interactions between these elements;
  - Its boundary, which determines whether an entity belongs to the system or not
- A system interacts with its environment: The environment acts on the behavior of the system which, in turn, reacts on this environment.
- In practice, what is meant by “the system” depends on the objectives of a particular study.




A conceptualization of a system

- In practice, what is meant by "the system" depends on the objectives of a particular study: The collection of entities that comprise a system for one study might be only a subset of the overall system for another.

- **Example 1:** If we want to study a **city's transportation network,** the entities of the system can be defined depending on the study's specific objectives:

  - **Traffic Flow Optimization:** If the primary goal of the study is to optimize traffic flow within the city, "the system" may be defined as the **road network**, **traffic signals**, and vehicles. The study might concentrate on improving traffic management strategies, signal timing, and road design to reduce congestion.

  - **Public Transportation Optimization :** Another research project may aim to enhance the city's public transportation system. In this case, "the system" could defined as **road network**, **buses**, **tramways**, **subways** (metro), and **related infrastructure** (bus stop, metro station, etc.).

- **Example 2:** If one wants to study a **bank** to determine the number of tellers needed to provide adequate service for customers who want just to cash a check or make a savings deposit: The system can be defined to be that portion of the bank consisting of the **tellers** and the **customers** waiting in line or being served.

## 1.2. Components of a System

In order to understand and analyze a system, a number of terms need to be defined:

- **Entity:** an entity is an object of interest in the system.
- **Attribute:** an attribute is a property of an **entity**.
- **Activity:** an activity represents a process causing changes in a system.
- **State variable:** a state variable is a particular measurable property of an object or system.
- **State of a system:** The state of a system is defined to be that collection of variables necessary to describe the system at any time.
- **Event:** An event is an instantaneous occurrence that might change the state of the system (state variables).
  - **Endogenous** is used to describe **activities** and **events** occurring within a system,
  - **Exogenous** is used to describe **activities** and **events** in the environment that affect the system.
- **The external behavior** of a system is the relationship it imposes between its input time histories and output time histories.
- **The internal structure** of a system includes its state and state transition mechanism (dictating how inputs transform current states into successor states).
- **Knowing the system structure allows us to deduce (analyze, simulate) its behavior.**

## 1.2. Components of a System

**Example 1:** If a Bank is being studied system:

- Customers might be one of the **entities**,
- The balance in their accounts might be an **attribute**,
- Making deposits might be an **activity**.
- Possible **state variables** are the number of busy tellers, and the number of customers waiting in line or being served.
- The **arrival of a customer** is an **exogenous event** and the **completion of service** of a customer is an **endogenous event**.

**Examples 2:** systems and state variables

| System | State variables |
|---|---|
| **The Solar System** | position, velocity, acceleration |
| Financial market | interest rates, stock prices, prices of goods and services, etc. |
| Queue | number of customers in queue, waiting time, arrival rate of customers, service rate |
| Weather system | air temperature, atmospheric pressure, humidity, wind speed and direction, etc. |
| Fluid dynamics | pressure, velocity, and density of the fluid |

# 1. SYSTEM

## *Discrete-event and continuous systems*

**Systems can be categorized as discrete or continuous:**

- **Discrete-event system:**

A system in which the state variables change instantaneously at discrete points in time,

**Example:**

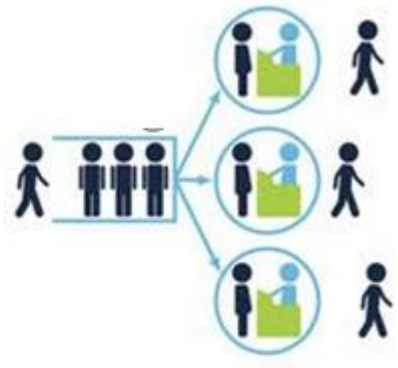
The queue of customers in a bank: The number of customers waiting in the queue changes at different points in time. It increases as new customers arrive and decreases as customers depart after receiving service.

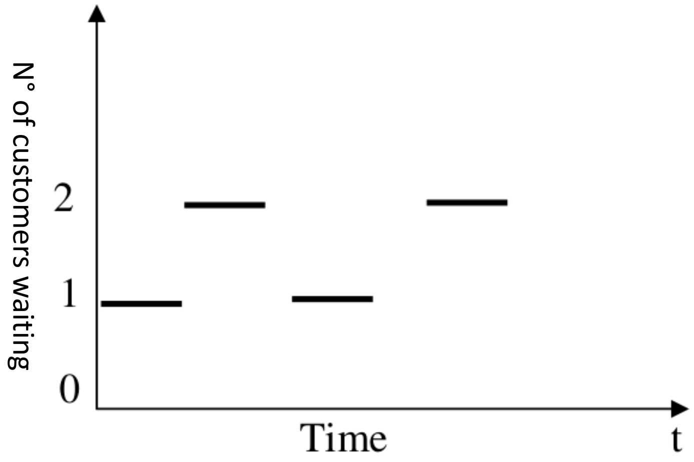
- **Continuous system:**

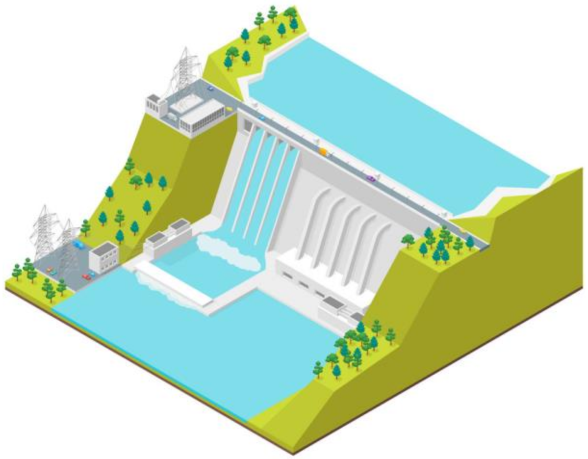
A system in which state variables change continuously over time,

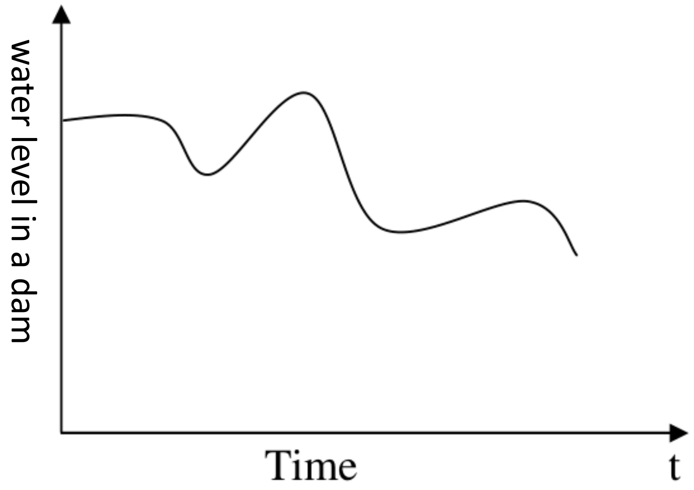
**Examples**

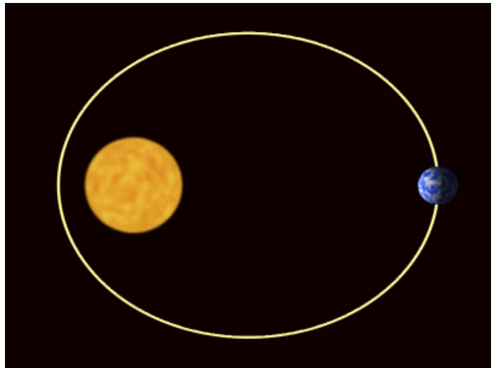
- Water level in a dam
- Airplane moving is an example of a continuous system : state variables such as position and velocity can change continuously in time.
- Planetary motion: is an example of a continuous system : position of the planets change continuously in time.

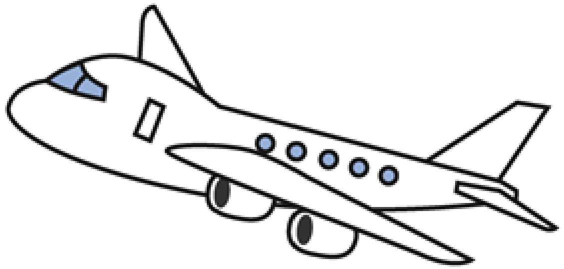








Systems can be categorized as **discrete** or **continuous**:

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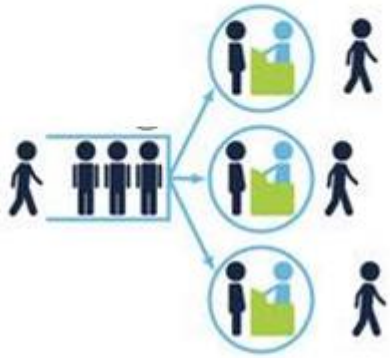
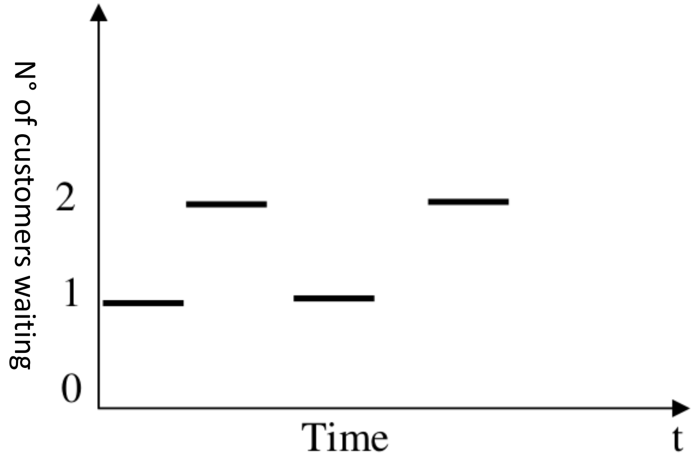
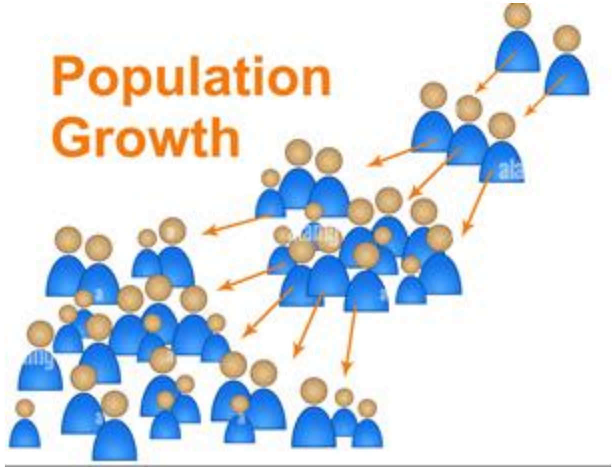





**Population growth:** can be viewed as a discrete system, the growth of a population is a series of discrete events, such as birth, death, and migration. Population size changes at discrete times when these events occur.

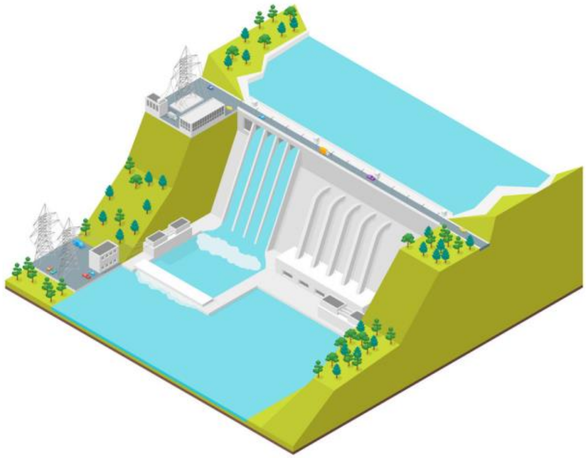


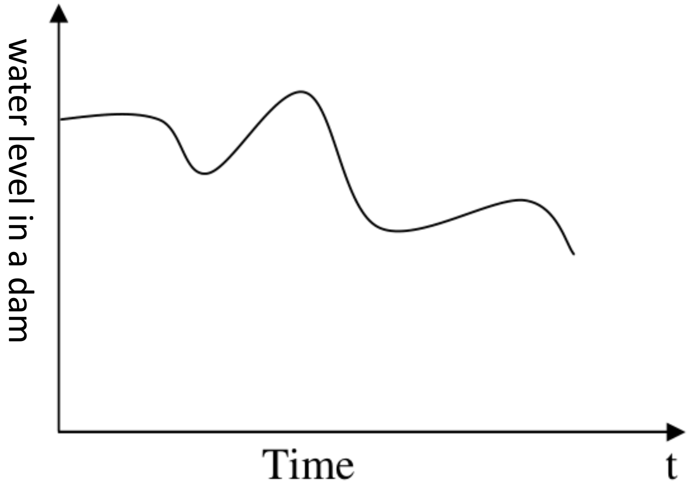
**Continuous system:**

A system in which state variables change continuously over time,

**Examples**

- Water level in a dam is an example of a continuous system: a level of water change continuously in time.



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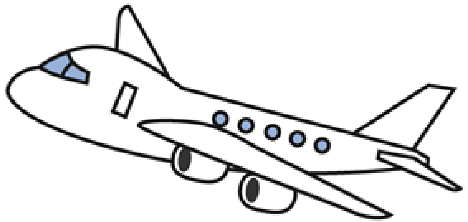
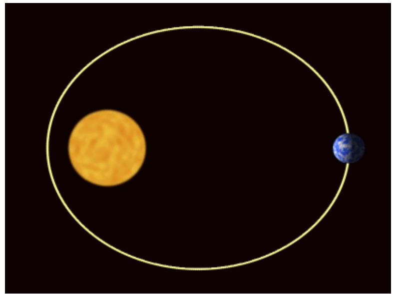




- Studying a system consists of understanding the relationships between its components and predicting system behavior ;
- To study a system, it is sometimes possible to experiment with the system itself.

**Definition.** An experiment is a process by which we collect data on a system by acting on its inputs

- However, it is not always practical or possible to perform experiments on the system.

**Examples:**

- It is impossible to conduct experiments on celestial objects like stars or planets.
- Conducting large-scale experiments on the Earth's environment, such as deliberately polluting a natural ecosystem, is both impractical and harmful.
- In the case of a bank, reducing the number of tellers to study the effect on the length of waiting lines, can lead them to switch banks.
- Etc.

- Hence, system studies often use **models**.

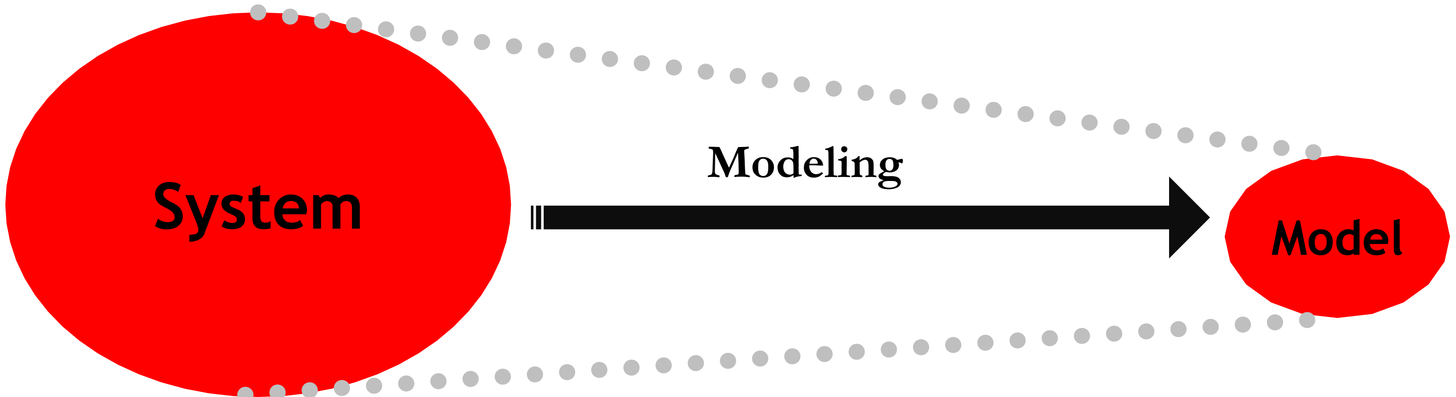
## 2.1. Definitions

**Definition 1.** A model is a representation of a system for the purpose of studying the system.

- The model, by definition, is a simplification of the system.
- It is necessary to consider only those aspects of the system that affect the problem under investigation.

**Definition 2.** In the context of Modeling and simulation:
A model **M** of a system **S** for an experiment **E** is anything to which we can apply **E** to answer questions concerning **S**.

**Definition 3.** Modeling is the activity of building models



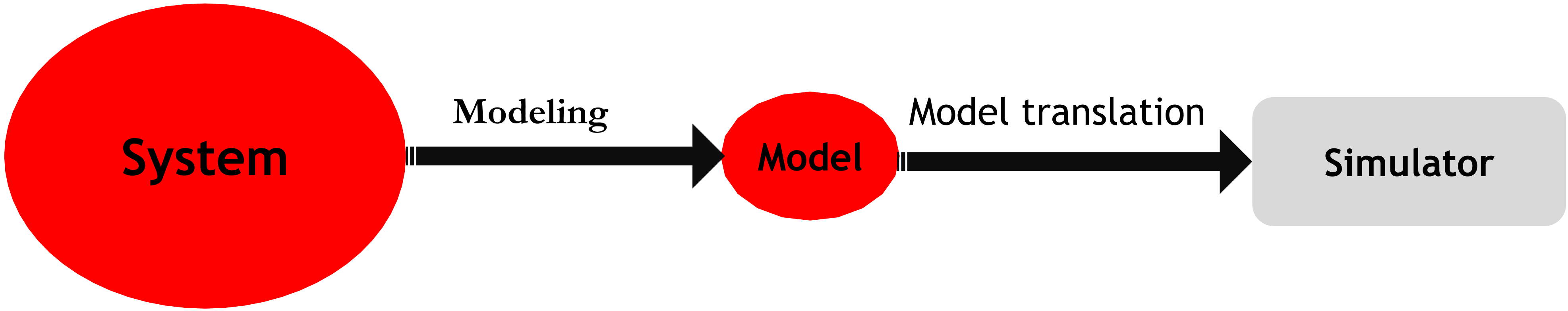
# 2. Model of a System

## 2.1. Definitions

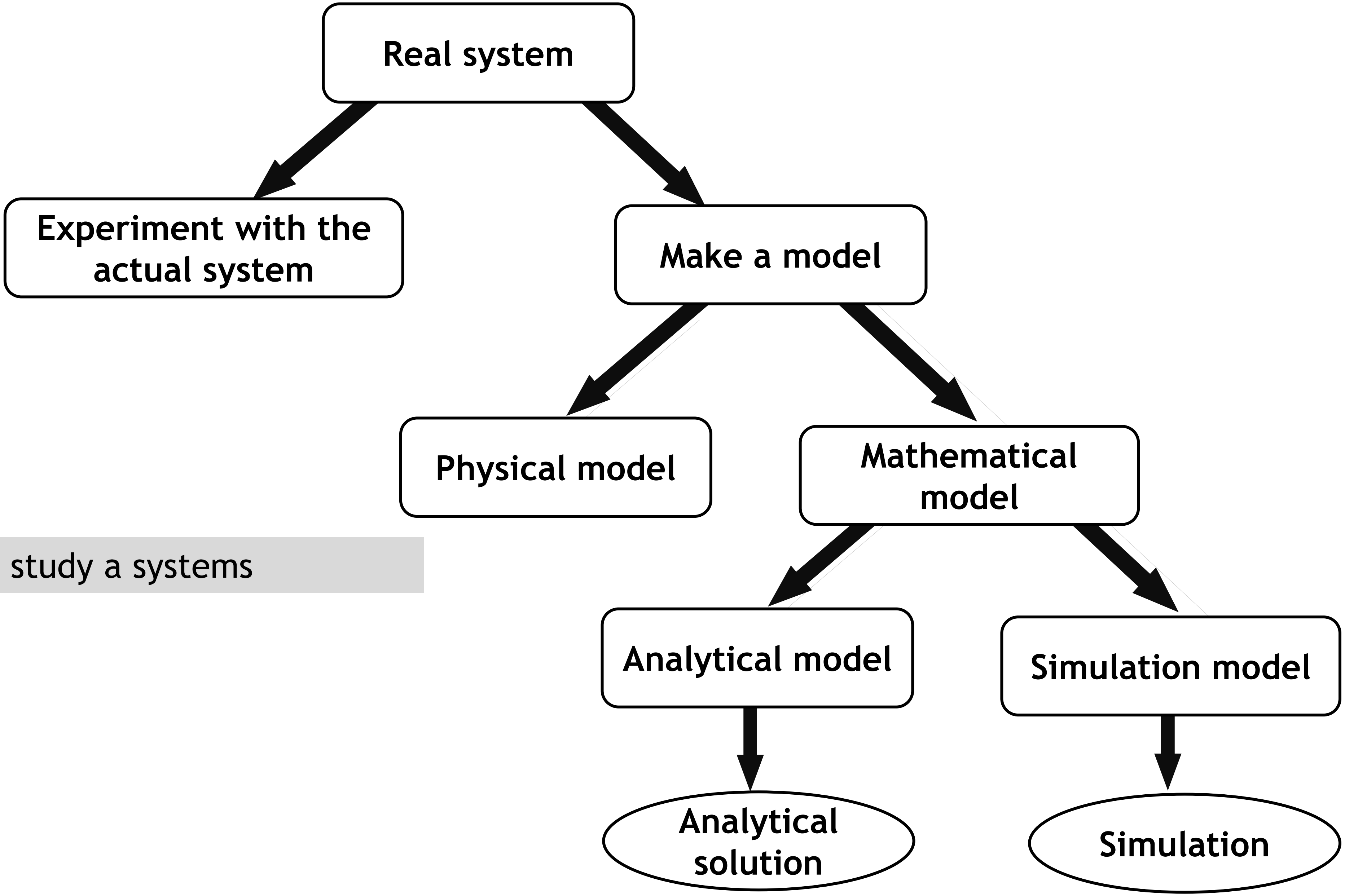
**Definition 1. Simulation** is the reproduction of the dynamic behavior of a real system based on a model

**Definition 2.** A **simulator** is the translation into computer programs (algorithms) of the dynamic behavior of a model

**Definition 3.** Computer simulation is the reproduction of the dynamic behavior of a real system based on a model



# 2.1. Definitions




Ways to study a systems

## 2.2.1. Physical and mathematical models

- **Physical models** are physical scaled-down representations of systems, or phenomena that are used for various purposes, including experimentation, education, etc.

*Examples*:

**Wind Tunnel Models:** Engineers use scale models of aircraft, cars, and buildings in wind tunnels to study aerodynamics, airflow, and structural integrity. These models help in optimizing designs.

**Hydraulic Models:** Physical hydraulic models to simulate the behavior of water flow in rivers, reservoirs, etc. These models help in designing flood control systems.


- **Mathematical models** are a representation of a real systems using mathematical equations, expressions, symbols, and relationships.

*Example*: The equation **d = r * t** represents a simple relationship between distance (d), rate or speed (r), and time (t).

## 2.2.2. Analytical and simulation models

- **Analytical models**
  - Are mathematical representations of a system or a problem (e.g. differential equations) derived from physical laws or well-established theoretical relationships
  - They often can be solved explicitly using mathematical methods to predict the behavior of the system
  - Analytical modes are generally limited to simple or idealized systems due to the complexity of the equations and the difficulty in solving them for complex systems.

  **Example**: $d = r \times t$ is a mathematical formula that relates distance, rate, and time. It can be used to calculate any of the three variables if the other two are known. Where *d* is the distance traveled, *r* is the rate of speed, and *t* is the time spent traveling. This equation is:

    - A valid model in some instances (For example: a space probe after it has attained its flight velocity)
    - A very poor model for other purposes. For example: the arrival time of a bus on congested urban freeways

- **Simulation models.**
  - Most real-world systems are too complex for which analytical models are not feasible
  - Simulation models are computational approximations of real systems created through mathematical modeling using a computer program.
  - In a simulation we use a computer to evaluate a mathematical model numerically, and data are gathered in order to estimate the desired
  - Simulation models make it possible to study the behavior of a system under different conditions, explore hypothetical scenarios and observe results that cannot be obtained by direct analytical approaches.

## 2.2.3. Static and Dynamic models

- **Static simulation models** : A static simulation model is a representation of a system at a particular time or one that may be used to represent a system in which time simply plays no role.
- **Examples** of static simulations include **Monte Carlo simulations** applied to financial risk analysis, system reliability analysis, etc.
- **Dynamic simulation models**: represent systems as they change over time.
- **Example** of a dynamic simulation: The simulation a queue in a bank from 9H:00 to 16H:00 ,

## 2.2.4. Deterministic and Stochastic

- **Deterministic simulation models** contain no random variables. Deterministic models have a known set of inputs that will result in a unique set of outputs.
- **Stochastic simulation models** have one or more random variables as inputs. Random inputs lead to random outputs.

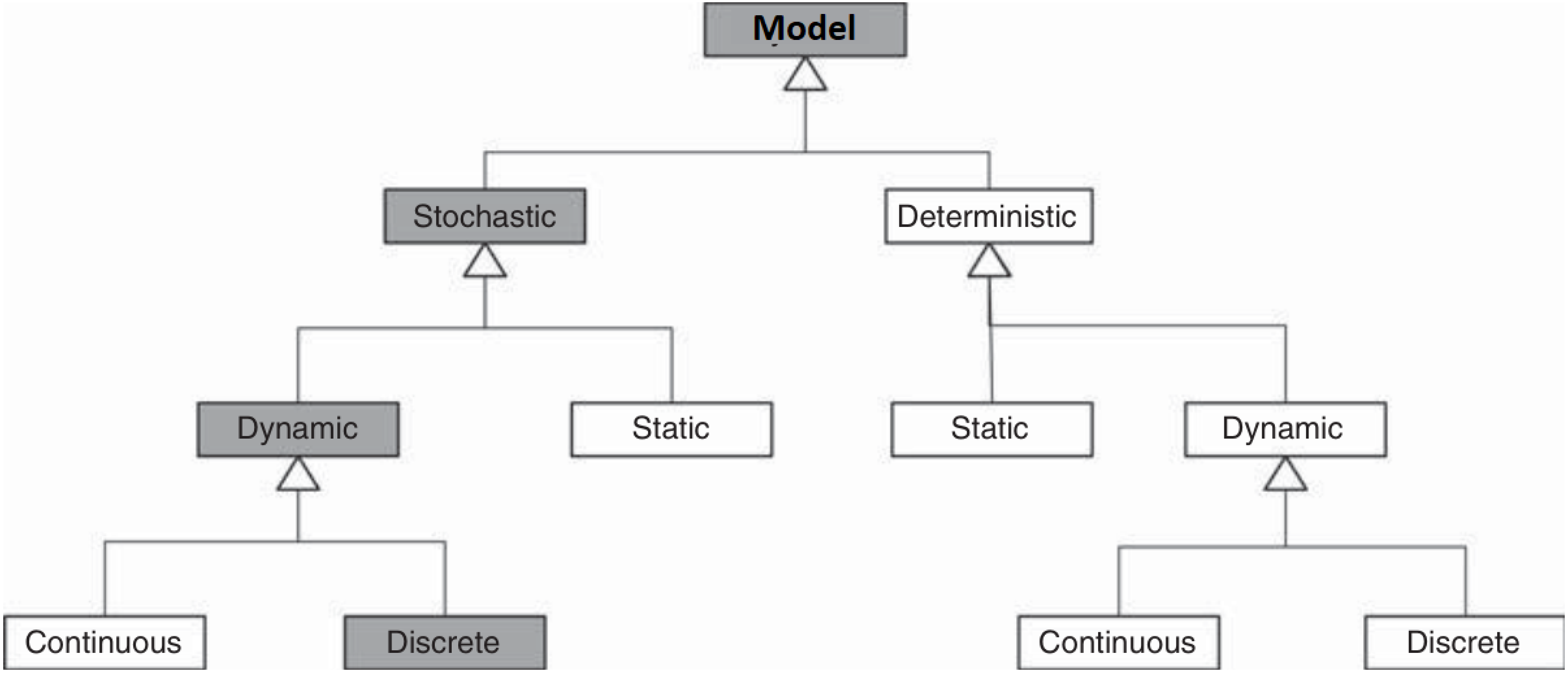
## 2.2.5. Discrete and continuous models

- **Discrete model:** in which the state variables change instantaneously at discrete points in time,
- **Continuous models:** in which state variables change continuously over time.

*Note: Discrete model can be used to model a continuous system, and continuous model can be used to model a discrete system.*

## 2.2. Types of Models

This course primarily examines stochastic, dynamic, and discrete modeling.



**Definition.** A modeling paradigm is a set of concepts, laws and means aimed at defining models.

- **Examples of modeling paradigms:**
  - Differential equations ;
  - Markov chains and queuing theory;
  - Discrete-Event Simulation
  - Petri net
  - Cellular automata;
  - Multi-agent systems
  - etc.

# Some citations regarding modeling and simulation

- Mathematical models are caricatures of real systems that aim to capture the fundamental mechanisms of some process in order to explain observations or predict outcomes.

  —*István Z. Kiss, Joel C. Miller, Péter L. Simon*

- Models are not reality. They are tools for helping us understand reality.

  — *Jay W. Forrester,*

- All models are wrong, some are useful.

  — *George E.P. Box*

- As far as the laws of mathematics refer to reality, they are not certain, and as far as they are certain, they do not refer to reality.

  — *Albert Einstein*

# 4. Steps in a Simulation Study

**Steps in a Simulation Study**